Chaotic properties in musical sounds

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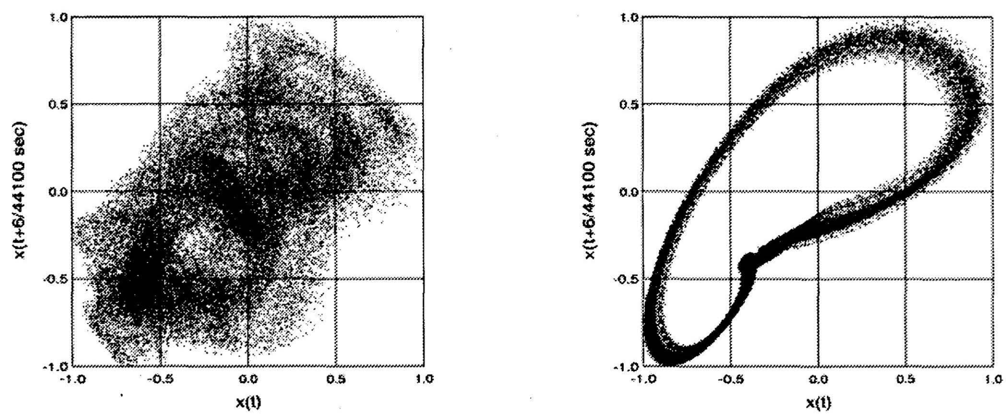
Tested data

It is a interesting question whether sounds of musical instruments are chaotic or not. It is hard to find studies about chaotic properties of musical instruments except only in clarinet, in human voice, and in cymbal. We decided to analyze the sounds of musical instruments which are collected in the Real World Computing (RWC) data base[1, 2] as time series data. The analyzed instruments include the piano, the harpsichord, the pipe organ, the hammond organ, the accordion, the harmonica, the guitar, the violin, the viola, the trumpet, the trombone, the French horn, the saxophone, the oboe, the English horn, the bassoon, the clarinet, the flute, the panpipes, the recorder, the shakuhachi, the shamisen, the koto, the shou, the samba whistle, the whistle, and the human voice. The recorded frequency is 44.1 kHz. We used the sounds of 440 Hz pitch (tone "A").

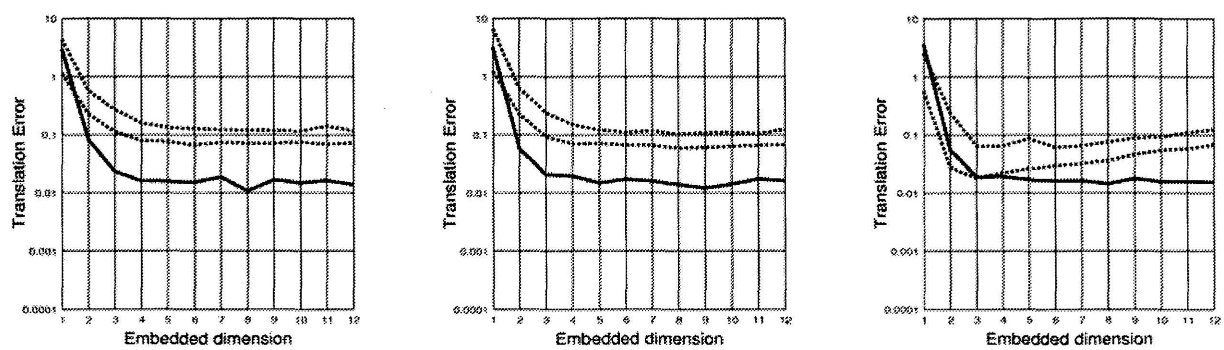


(a) The violin (b) The trombone

Fig. 1: Samples of attractor shapes.

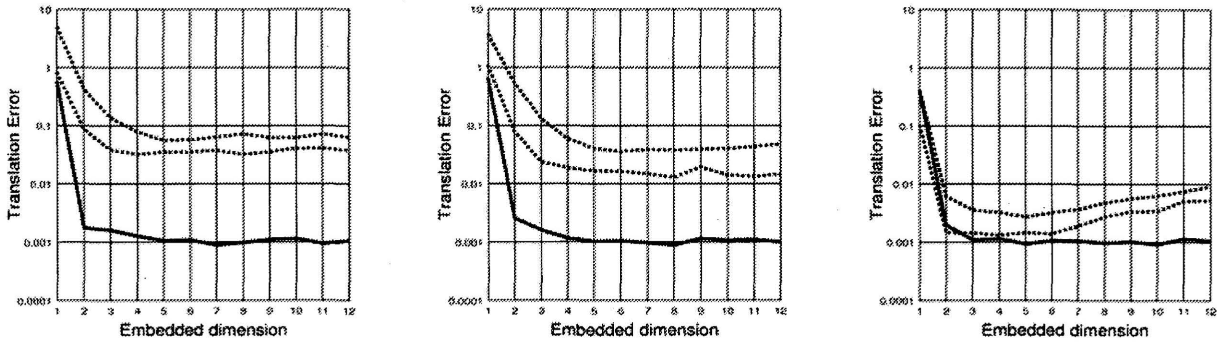
Surrogate tests

We used three different surrogate tests with the Wayland statistic[3] as a test statistic. The results of phase-randomized Fourier-transform surrogates(PR)[4], iterative amplitude adjusted Fourier transform surrogates(IA)[5], and pseudo-periodic surrogates(PPS)[6] in violin sounds and trombone sounds are presented in Figs. 2 and 3. In these figures, the solid lines indicate the test statistic for the original dataset. These lines, for most embedding dimensions, are out of the intervals indicated by the two dashed-dotted lines, which indicate the maximum and minimum values obtained using the 39 surrogate datasets for the test statistic. The results show that sounds of musical instruments are nonlinear and have determinism beyond pseudo-periodicity, which are consistent with deterministic chaos.



(a)PR (b)IA (c)PPS

Fig. 2: Results of surrogate tests of violin sounds.



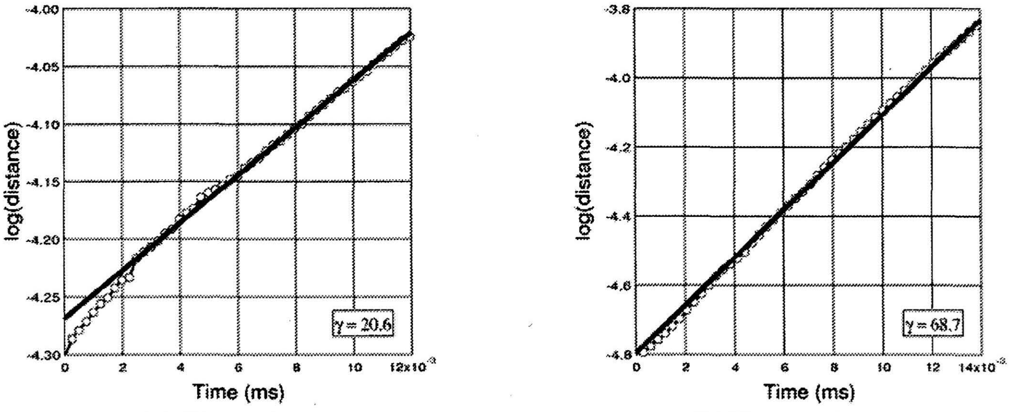
(a)PR (b)IA (c)PPS

Fig. 3: Results of surrogate tests of trombone sounds.

Estimation of the maximal Lyapunov exponent

To confirm chaotic properties, we estimated the maximal Lyapunov exponent using the method proposed by Kantz[7]. The estimation process is given as follows. (1) We selected a point in the d-dimensional delay space, and n of its neighboring points. In this study, n is 8 fixed. (2) Then, we calculated the average distance "l" between the selected point and the neighboring points. (3) Finally, we investigated the change in the distance l with time using a logarithmic plot. If the logarithmic plot shows a linear part that is about to saturate, the slope of linear part gives the maximal Lyapunov exponent.

As shown in Fig. 4, the exponents had positive values for sounds of many instruments. This indicates that sounds of musical instruments might be deterministic chaos, however it does not necessarily mean that the sounds are low-dimensional chaos. These results are presented for the degree of Ph.D[8].



(a) The violin (b)The trombone

Fig. 4: Distance between a selected point and neighboring points in delay space.

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